2.4 A Closer Look at Forces and Newton's Third Law

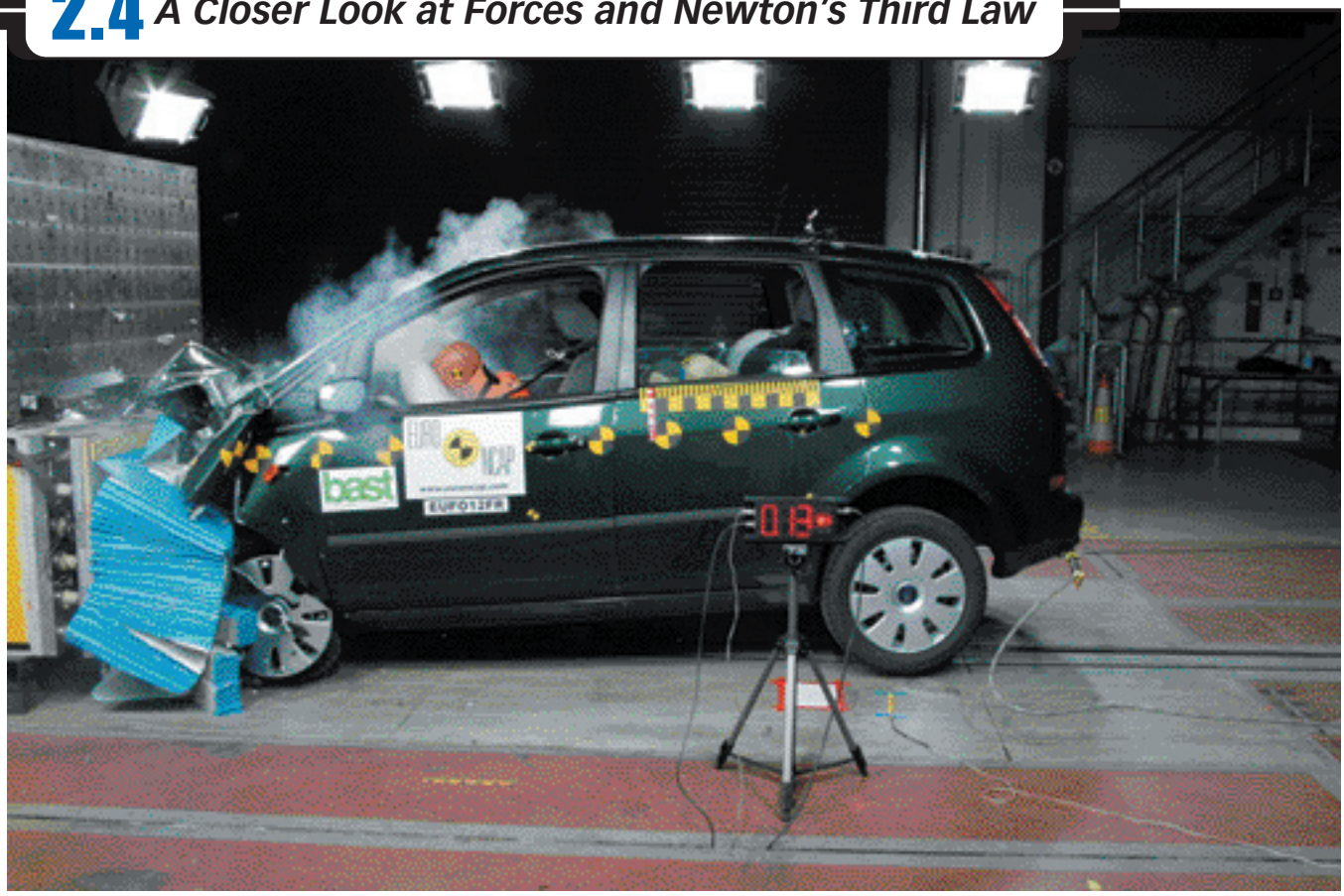


Figure B2.10: The deployment of the air bag uses Newton's laws of motion to reduce injury in a collision.

Vehicle collisions, even at slow speeds, can result in serious injuries for the driver and passengers. Knowledge of Newton's laws of motion are fundamental in designing safety features that reduce damage and injury in automobile collisions. Did you know that the collision of a vehicle actually involves three collisions? The three classes of collisions are

- **primary collision:** the vehicle colliding with another object, such as another vehicle
- **secondary collision:** the occupant colliding with the interior of the vehicle
- **tertiary collision:** the occupant's internal organs colliding within the occupant's body

Specific safety features are designed to address each type of collision.

Practice

15. The technologies identified in the following table are designed to reduce injury in a motor vehicle collision. Identify the class of collision for which each technology is designed.

Safety Technology	Class of Collision
shock-absorbing bumpers	
crumple zones (in the frame)	
padded dashboard, steering wheel, etc.	
seat belts	
air bags	

Newton's Third Law

The primary collision stops the vehicle almost instantly; however, the occupants of the vehicle remain in motion at the same speed due to their momentum. As the occupants continue to move after the vehicle has stopped, the impulse that results when the occupants collide with the interior parts of the vehicle determines the extent of their injuries. Without safety features like those described in Practice question 15, the time interval for the impact would be extremely small, resulting in a very large force exerted by the vehicle on the occupants. It is quite evident that the vehicle must exert a force on an occupant of the vehicle; however, did you know that the occupant exerts a force of the same magnitude on the vehicle? Can you identify evidence that supports this statement in Figure B2.11?

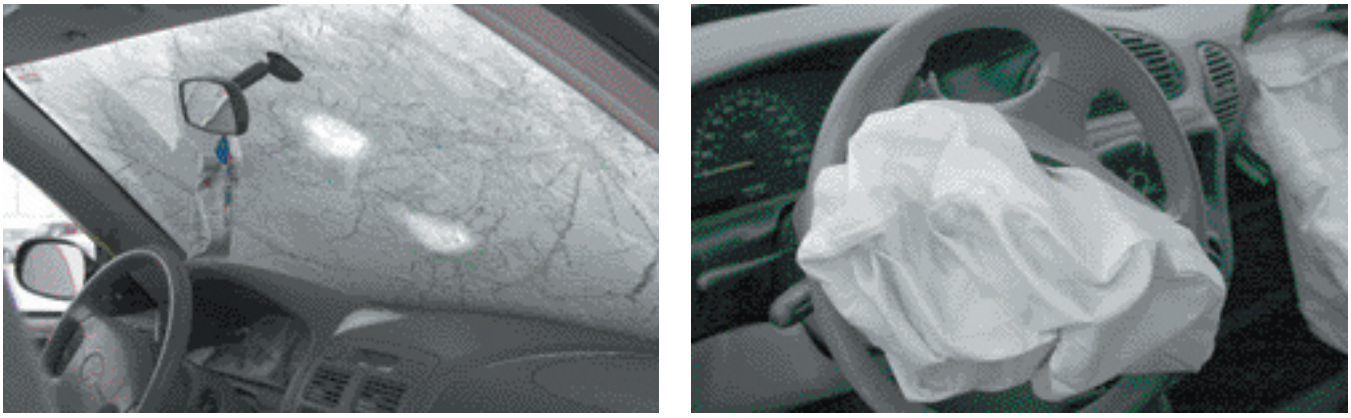


Figure B2.11: The force exerted by the driver onto the vehicle smashed the windshield and compressed the air bag.

It was the force exerted by the occupant that smashed the windshield and compressed the air bag. A similar process occurs when a person jumps off a skateboard. In this case, one force is exerted by the person on the skateboard and the other force is exerted by the skateboard on the person.

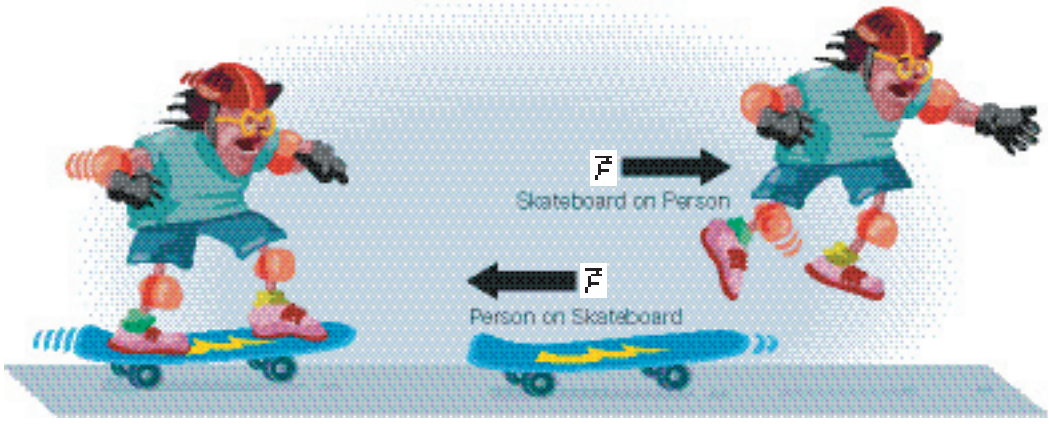


Figure B2.12: When a person jumps horizontally off a skateboard, a force is exerted on the skateboard, propelling the board backward. The skateboard must exert the same force on the person, pushing the person forward.

Examples like the person and the skateboard illustrate some interesting properties of forces:

- When the person and the skateboard interact, the forces always occur in pairs. The person exerts an action force on the skateboard, and the skateboard exerts a reaction force on the person. These forces are an example of an action/reaction pair.
- The forces have the same magnitude, but push in opposite directions. The action force that pushes the skateboard backward is the same size as the reaction force that pushes the person forward.
- The forces in an action/reaction pair push on different objects. One force pushes on the skateboard, the other pushes on the person.

These properties have been summarized in **Newton's third law of motion**. The following equation is a convenient way to summarize the idea that the force of object 1 on object 2 is equal in magnitude, but opposite in direction, to the force of object 2 on object 1.

Newton's third law of motion: a law stating that whenever one object exerts a force on a second object, the second object exerts an equal but opposite force on the first object

$$\vec{F}_{1 \text{ on } 2} = -\vec{F}_{2 \text{ on } 1}$$

In everyday speech, Newton's third law is sometimes summarized by saying that for every action force, there is an equal but opposite reaction force. This version of Newton's third law is concise, but it neglects to mention that the forces in the action/reaction pair act on different objects.

Example Problem 2.9

Identify the action and reaction forces in the illustration the skaters as the skater on the right pulls on the rope.

Solution

When the skater on the right pulls on the rope (the actio force), the skater on the left moves towards him becaus of this force. The skater on the left also exerts an equal but opposite force (the reaction force) on the skater on right. The skater on the right also moves because of this reaction force.

Figure B2.13: The action force was exerted by the swimmer on the wall of the pool. The reaction force was exerted by the wall of the pool on the swimmer.

Practice

16. Identify the action force and reaction force in the following situations.
    a. a passenger colliding with a deployed air bag
    b. a car bumper colliding with a concrete barrier
    c. a swimmer pushes against the water
    d. a hiker pushes against the ground
    e. while moving forward, a car tire pushes against the ground

Confirming Newton's Third Law

Forces are the foundation of Newton's laws of motion, and an understanding of these laws will help you to understand how objects interact with each other. The significance of forces and the laws of motion as applied to the interaction of objects can be analyzed further using the applet "Newton's Laws and the Interaction of Objects."

Using this applet, you can enter the required data and the applet will provide you with an animated display of the event, along with corresponding data resulting from the event. An analysis of the resulting data can then be used to clarify the significance of Newton's laws of motion and the interaction of objects.

Utilizing Technology

Newton's Laws and the Interaction of Objects

Purpose

You will confirm your understanding of forces and motion using the applet "Newton's Laws and the Interaction of Objects" on the Science 20 Textbook CD.

Science Skills

- ✓ Performing and Recording
- ✓ Analyzing and Interpreting

Background Information

This applet shows a number of toy vehicles that are connected by a spring. The masses of the vehicles, the force exerted by the spring, and the time interval of the spring pushing on the vehicles are all variables that can be manipulated by the user. Before starting this activity, familiarize yourself with the features of the applet by entering values and clicking the Go button. Remember to click the Reset button before entering values for a new trial.

Procedure

step 1: Copy the following data sheet into your notebook or into a spreadsheet.

Newton's Laws and the Interaction of Objects

Constant Values

Time of Interaction = _____

Mass of Vehicle 1 = _____

Force on Vehicle 1 = _____

Acceleration of Vehicle 1 = _____

Velocity of Vehicle 1 = _____

Mass of Vehicle 2 (kg)	Force on Vehicle 2 (N)	Acceleration of Vehicle 2 (m/s^2)	Velocity of Vehicle 2 (m/s)
1.00			
2.00			
4.00			
5.00			
6.00			
8.00			
10.00			

step 2: Select the following constant values for Vehicle 1: Time of Interaction = 0.40 s, Mass of Vehicle 1 = 5.00 kg, and Force on Vehicle 1 = - 2.00 N. Record these values in the appropriate places on the data sheet. They will be kept constant throughout this investigation.

step 3: Set the mass of Vehicle 2 to 1.00 kg.

step 4: Click the Go button, and observe the motion of the vehicles. Record the acceleration and velocity of Vehicle 1 and the force, acceleration, and velocity of Vehicle 2.

step 5: Click the Reset button, and set the mass of Vehicle 2 to 2.00 kg.

step 6: Click the Go button, and observe the motion of the vehicles. Record the force, acceleration, and velocity of Vehicle 2.

step 7: Repeat steps 5 and 6 for Vehicle 2 masses of 4.00 kg, 5.00 kg, 6.00 kg, 8.00 kg, and 10.00 kg.

Analysis

1. Compare the force on Vehicle 1 to the force on Vehicle 2 for each trial.
2. Explain how your answer to question 1 confirms Newton's third law of motion.
3. Explain the significance of the negative sign in the force on Vehicle 1.
4. According to Newton's second law, an unbalanced force acting on a mass will cause the mass to accelerate in the direction of the force, $\vec{F} = m\vec{a}$.
   a. Confirm the acceleration value you recorded on the data sheet for Vehicle 1.
   b. Confirm each of the acceleration values you recorded on the data sheet for Vehicle 2.
   c. Explain the significance of the negative acceleration value for Vehicle 1 and the positive acceleration values for Vehicle 2.
5. Explain why the vehicles in each trial experience the same force but exhibit different accelerations.
6. According to your data, explain the relationship between the acceleration of the vehicles and their final velocities.
7. In each trial, which vehicle experienced the greater change in velocity?
8. Copy the following table into your notebook or into a spreadsheet. Use the data from the data sheet to complete the table.

Mass of Vehicle 2 (kg)	Momentum of Vehicle 1 After Spring Uncoils (kg·m/s)	Momentum of Vehicle 2 After Spring Uncoils (kg·m/s)	Impulse of Vehicle 1 After Spring Uncoils (N·s)	Impulse of Vehicle 2 After Spring Uncoils (N·s)
1.00				
2.00				
4.00				
5.00				
6.00				
8.00				
10.00				

9. Even though each vehicle experiences the same force, the vehicle with the smaller mass undergoes a greater change in velocity. Do your results verify this conclusion? Explain your answer.
10. State whether or not each vehicle in each trial experiences the same magnitude of the following quantities.
    a. force
    b. acceleration
    c. time of interaction
    d. final velocity
    e. impulse
    f. momentum
11. Explain any differences you noted in question 10.

2.4 Summary

Newton's third law of motion describes an interesting property of forces: whenever one object exerts a force on a second object, the second object exerts an equal but opposite force on the first object. The following equation summarizes this idea:

$$\vec{F}_{1 \text{ on } 2} = -\vec{F}_{2 \text{ on } 1}$$

This law was confirmed in an investigation in which you observed the forces that acted on two toy cars connected by a spring. This lesson provided a different perspective on the interaction of two objects. If the force and the time interval are the same for both objects, the impulse and the change in momentum must still be the same for both objects. However, if the masses are different, velocity and acceleration cannot be the same. The activity showed that when the force applied to two objects is the same in an interaction, the object with the smaller mass will experience a larger acceleration and attain a larger change in velocity. The object with the larger mass will experience a smaller acceleration and a smaller change in velocity. This also explains why occupants of a larger vehicle are less likely to receive serious injuries in a minor collision than occupants of a smaller vehicle.

2.4 Questions

Knowledge

1. State the three classes of collisions during a motor vehicle collision, and discuss each class. In which class(es) will an occupant of a vehicle receive an injury?

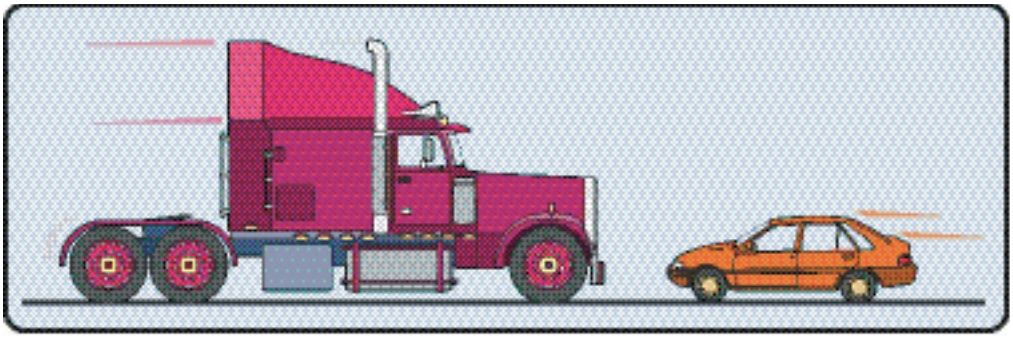
2. State Newton's third law in words and in equation form.

Applying Concepts

3. In an interaction between a large vehicle and a smaller vehicle, state whether or not the following quantities must be the same for each vehicle. Justify your answer.

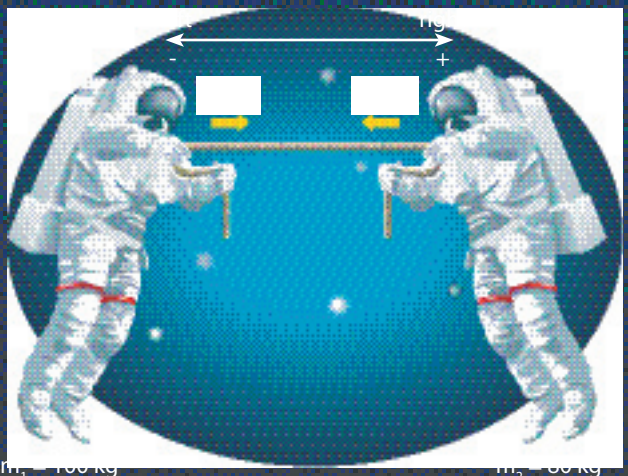
- mass
- velocity
- acceleration
- force
- time
- impulse
- change in momentum

4. The following diagram shows two objects approaching each other at the same speed.



a. Which vehicle will experience the greatest force?
b. Which vehicle will experience the greatest impulse?
c. Which vehicle will experience the greatest change in momentum?
d. Which vehicle will experience the greatest acceleration?
e. Which vehicle will experience the greatest change in velocity?
f. Which vehicle would you rather be in during the collision?

5. Two astronauts in space are attached by a rope. The mass of one astronaut is 100 kg; the mass of the other is 80 kg.



If the larger astronaut pulls on the rope with a force of 20 N for 0.20 s, determine the

a. force acting on each astronaut
b. acceleration of each astronaut
c. final velocity of each astronaut if they both start from rest
d. final momentum of each astronaut if they both start from rest
e. impulse acting on each astronaut

6. Imagine you are an astronaut on a spacewalk outside your capsule. You are attached to the capsule with a safety rope; however, the rope detaches from the capsule and you are floating freely in space. How could you use your knowledge of Newton's third law to assist your return to the capsule?